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Asao et al.

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(54) **NOISE REDUCTION APPARATUS**

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(30) **Foreign Application Priority Data**

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G10K 11/16 (2006.01)
G10K 11/178 (2006.01)

(52) **U.S. Cl.**

CPC ***G10K 11/16*** (2013.01); ***G10K 11/178*** (2013.01); *G10K 2210/1281* (2013.01); *G10K 2210/1283* (2013.01); *G10K 2210/3016* (2013.01); *G10K 2210/3214* (2013.01)

(58) **Field of Classification Search**

CPC G10K 11/178; G10K 2210/1281; G10K 2210/1283; G10K 2210/3016; G10K 11/16; G10K 2210/3214
USPC 381/71.1–71.12, 94.1–94.9
See application file for complete search history.

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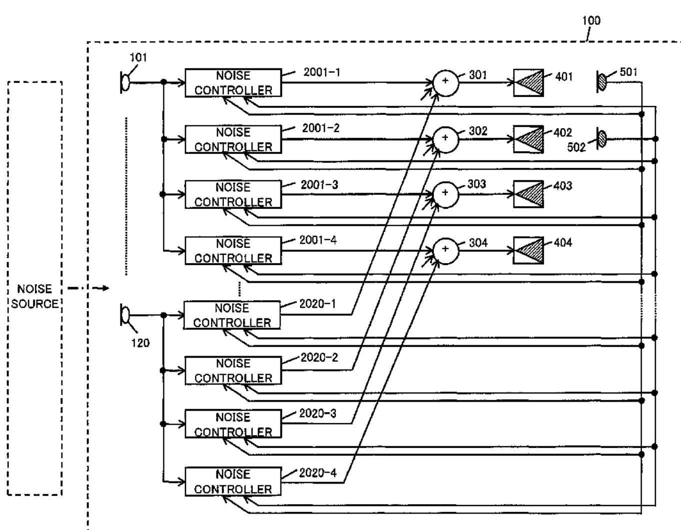
(57) **ABSTRACT**

A noise reduction apparatus includes a noise reduction amount calculator. The noise reduction amount calculator includes a difference calculator that obtains a difference between a level of the noise detected by a first noise detecting microphone and a level of the noise detected by a second noise detecting microphone when control sound is not output, a storage unit that stores the difference, an estimated noise value calculator that estimates a noise level that is to be detected by the second noise detecting microphone when the control sound is output, based on the level of the noise detected by the first noise detecting microphone when the control sound is output and the difference, and a reduction amount calculator that calculates a noise reduction amount on the noise reduction target position, based on the estimated noise value and the level of the noise detected by the second noise detecting microphone when the control sound is output.

9 Claims, 9 Drawing Sheets



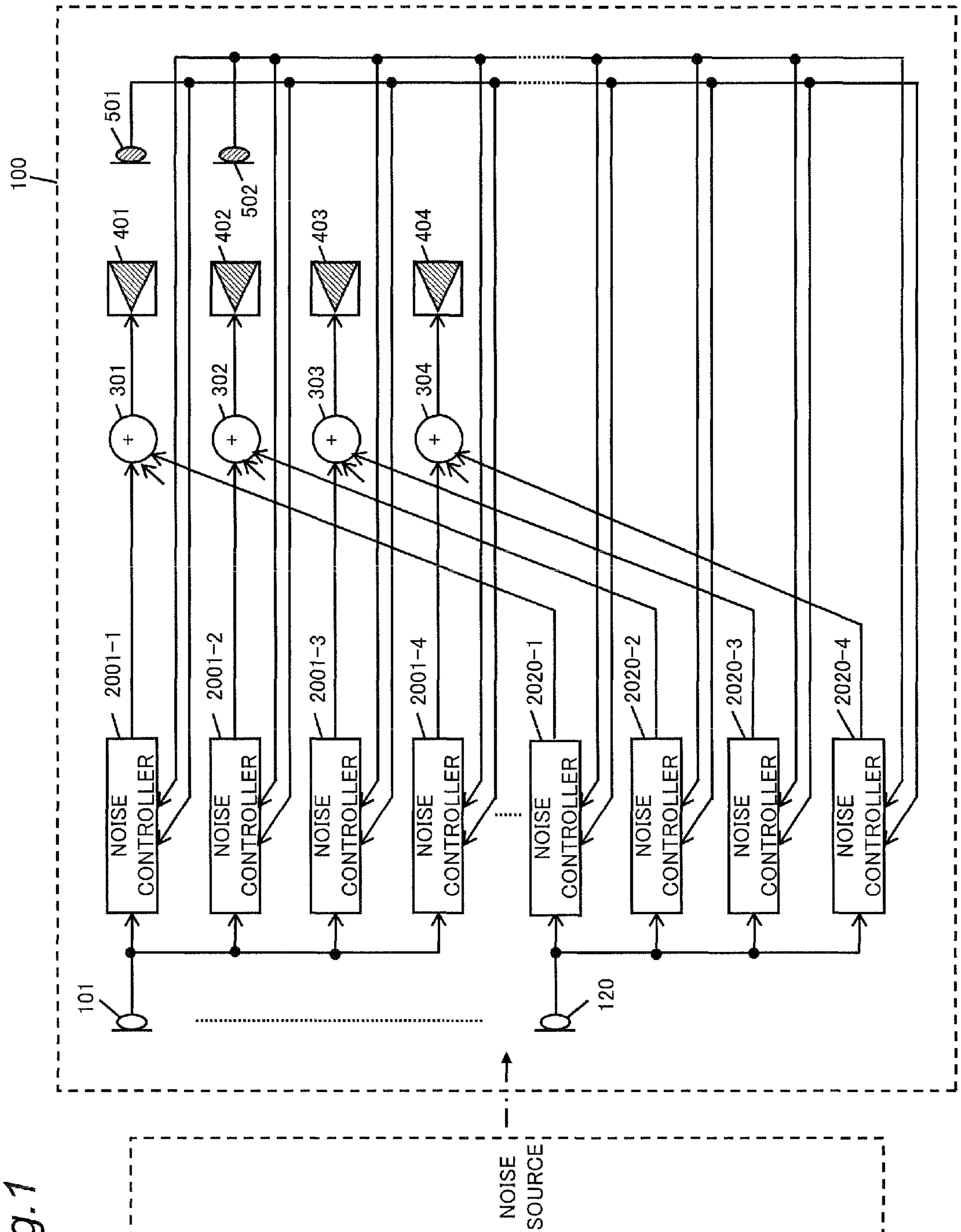

100
101
120
NOISE CONTROLLER
2001-1
2001-2
2001-3
2001-4
2020-1
2020-2
2020-3
2020-4
301
302
303
304
401
402
403
404
501
502
NOISE SOURCE

Fig.1

Fig.2A

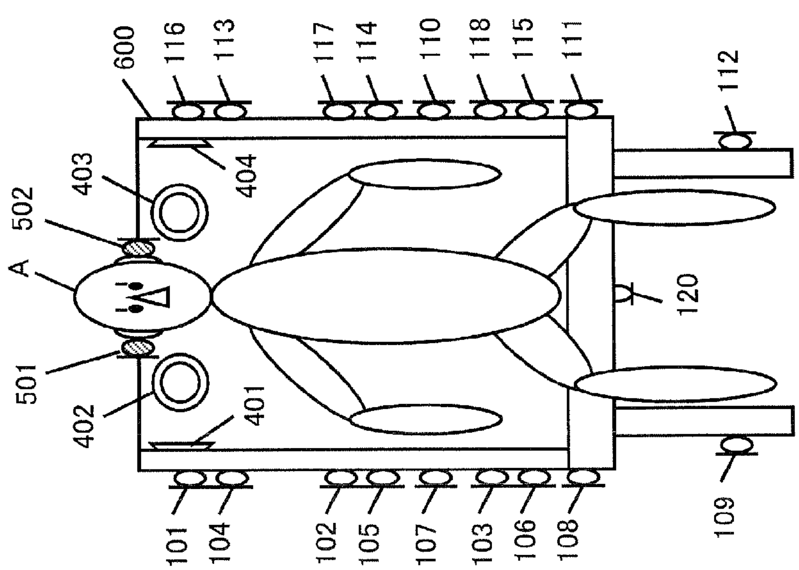


Fig.2B

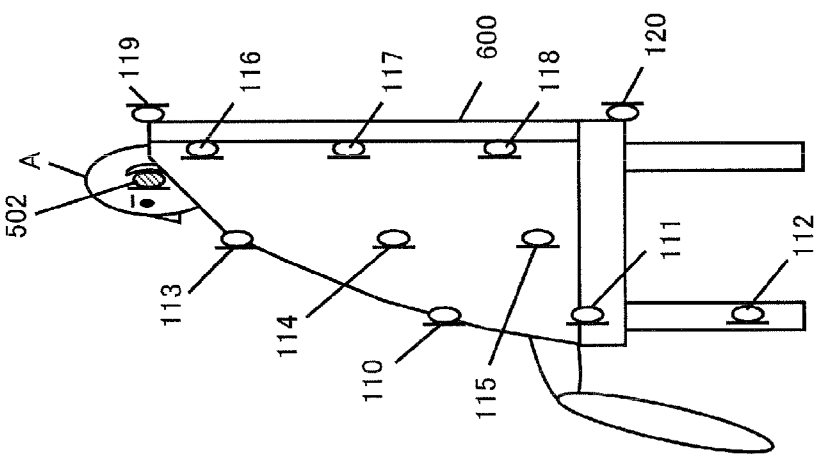
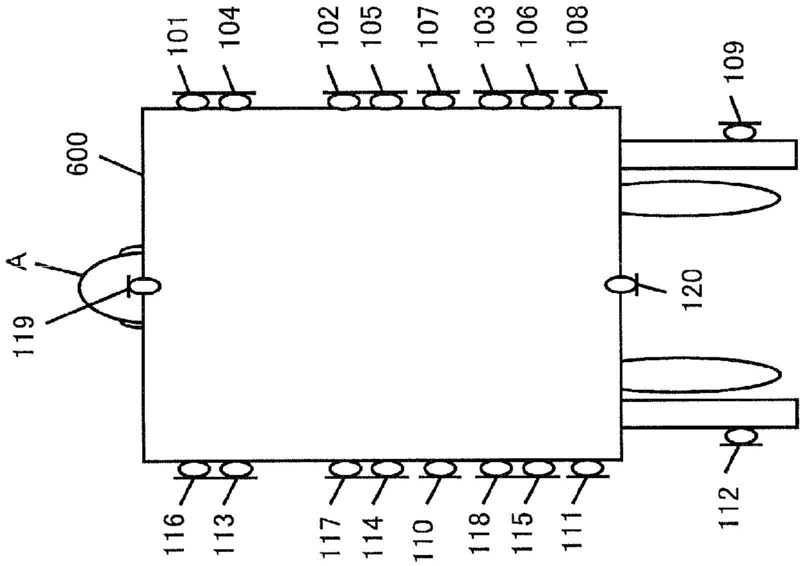


Fig.2C



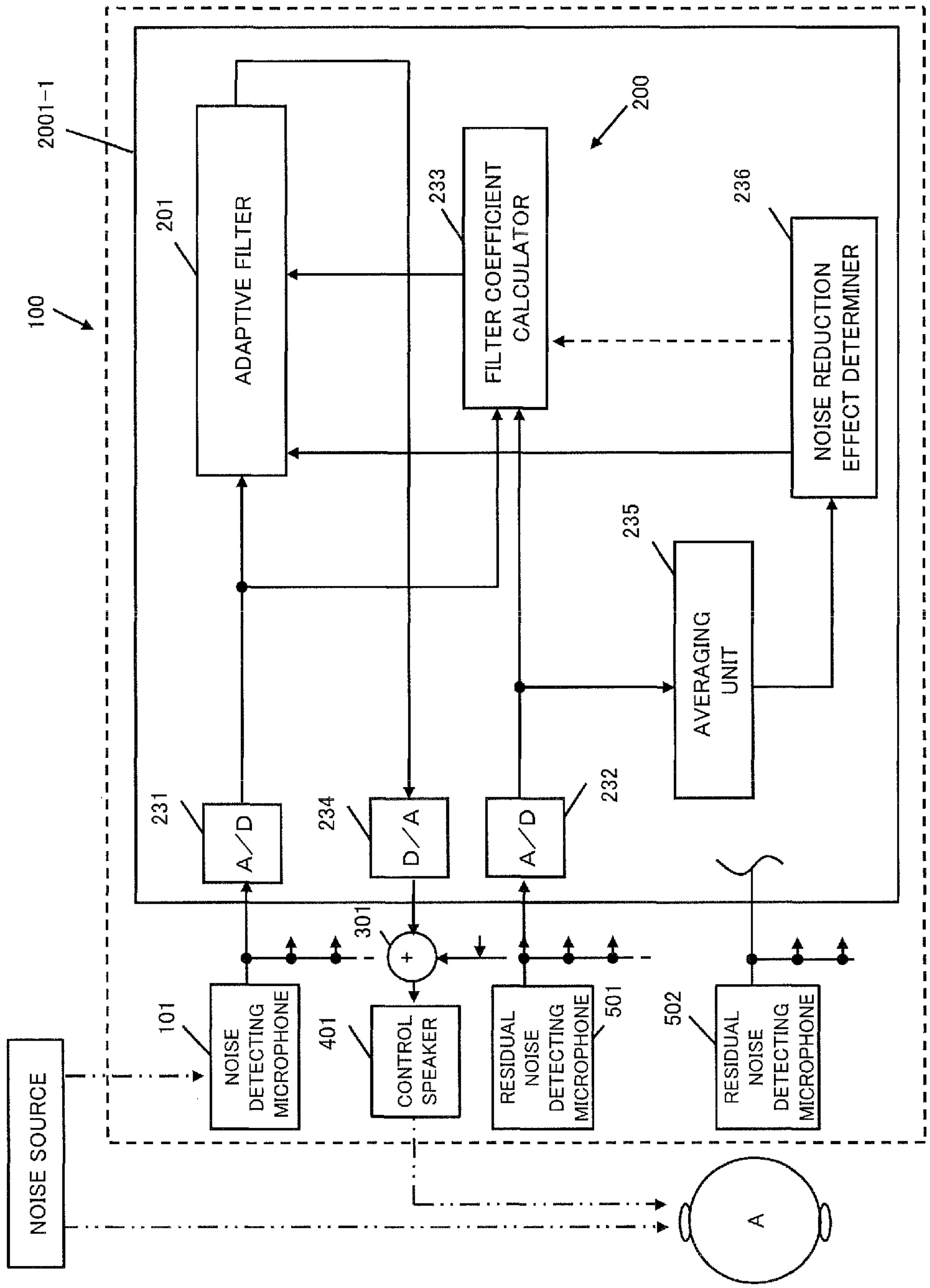

100
2001-1
200
201
ADAPTIVE FILTER
233
FILTER COEFFICIENT CALCULATOR
236
NOISE REDUCTION EFFECT DETERMINER
235
AVERAGING UNIT
231
A/D
234
D/A
232
A/D
301
+
101
NOISE DETECTING MICROPHONE
401
CONTROL SPEAKER
501
RESIDUAL NOISE DETECTING MICROPHONE
502
RESIDUAL NOISE DETECTING MICROPHONE
NOISE SOURCE
A

Fig.3

Fig.4A

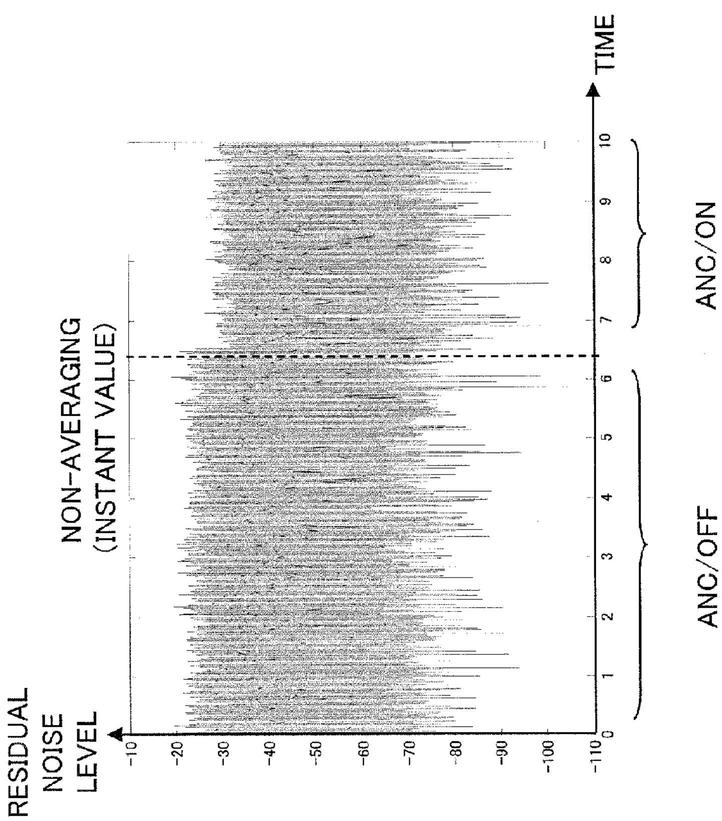
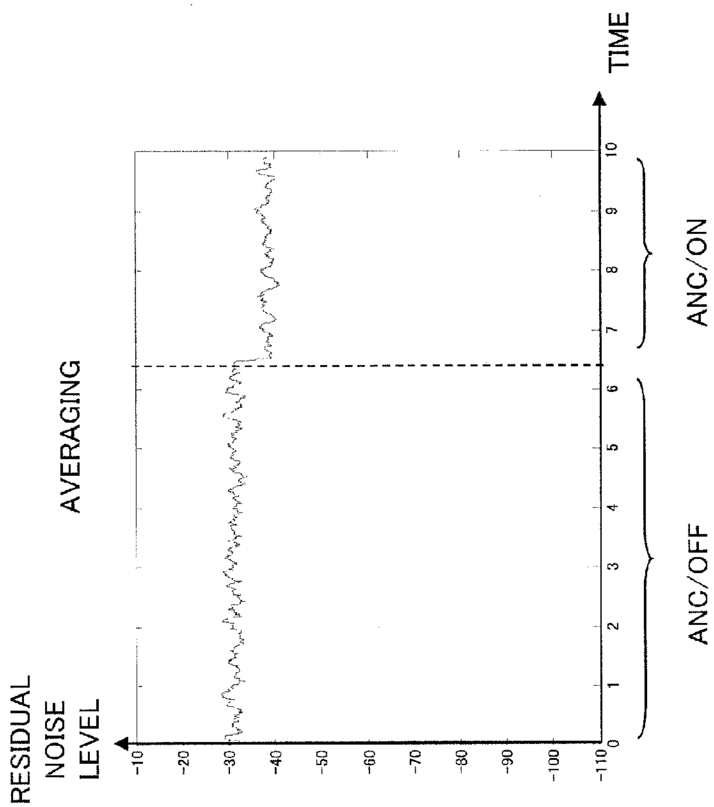
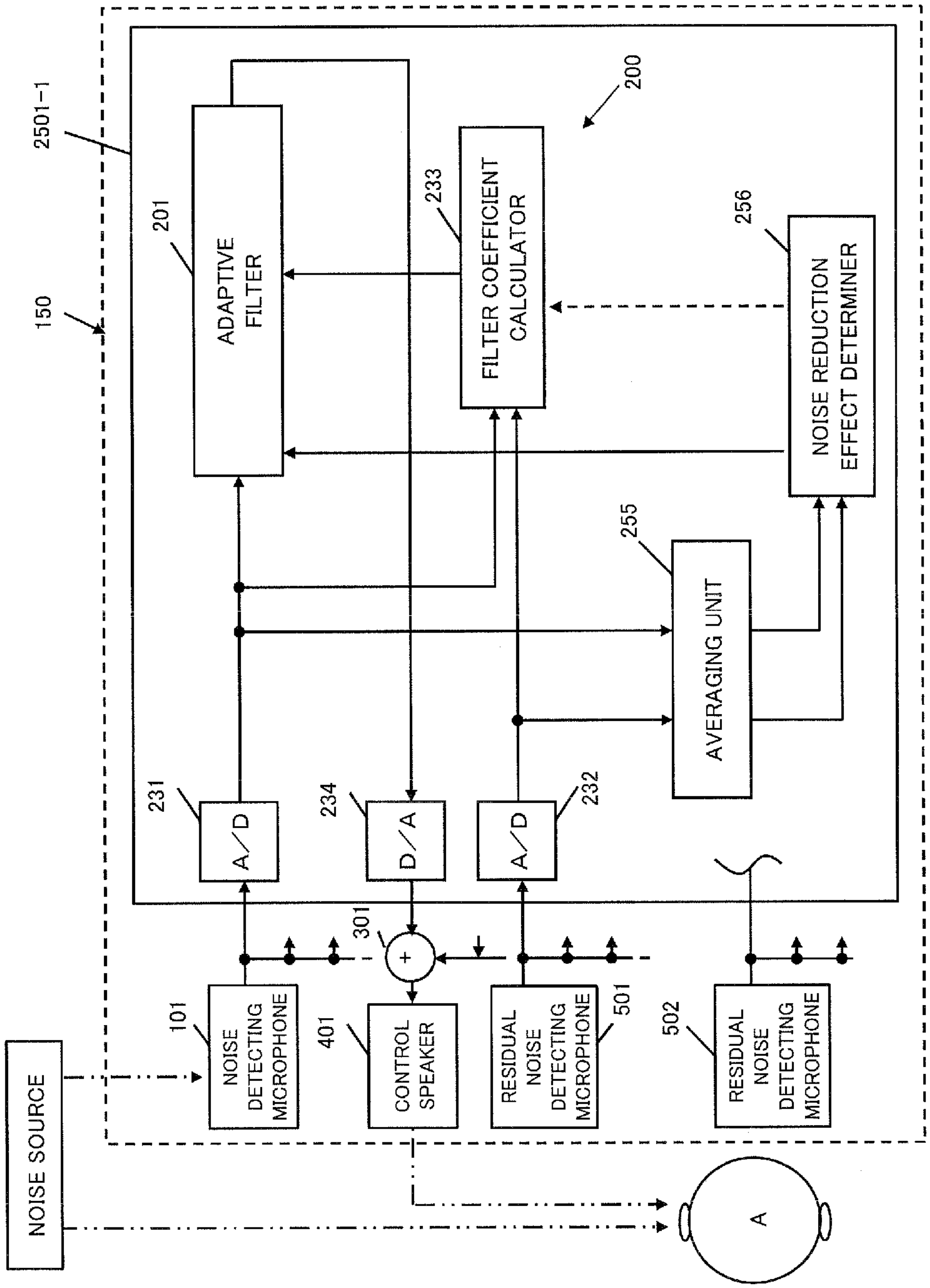

RESIDUAL NOISE LEVEL
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
0
1
2
3
4
5
6
7
8
9
10
TIME
NON-AVERAGING
(INSTANT VALUE)
ANC/OFF
ANC/ON

Fig.4B


RESIDUAL NOISE LEVEL
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
0
1
2
3
4
5
6
7
8
9
10
TIME
AVERAGING
ANC/OFF
ANC/ON



2501-1
150
200
201
ADAPTIVE FILTER
233
FILTER COEFFICIENT CALCULATOR
256
NOISE REDUCTION EFFECT DETERMINER
255
AVERAGING UNIT
231
A/D
234
D/A
232
A/D
301
+
101
NOISE DETECTING MICROPHONE
401
CONTROL SPEAKER
RESIDUAL NOISE DETECTING MICROPHONE
501
502
RESIDUAL NOISE DETECTING MICROPHONE
NOISE SOURCE
A

Fig.5

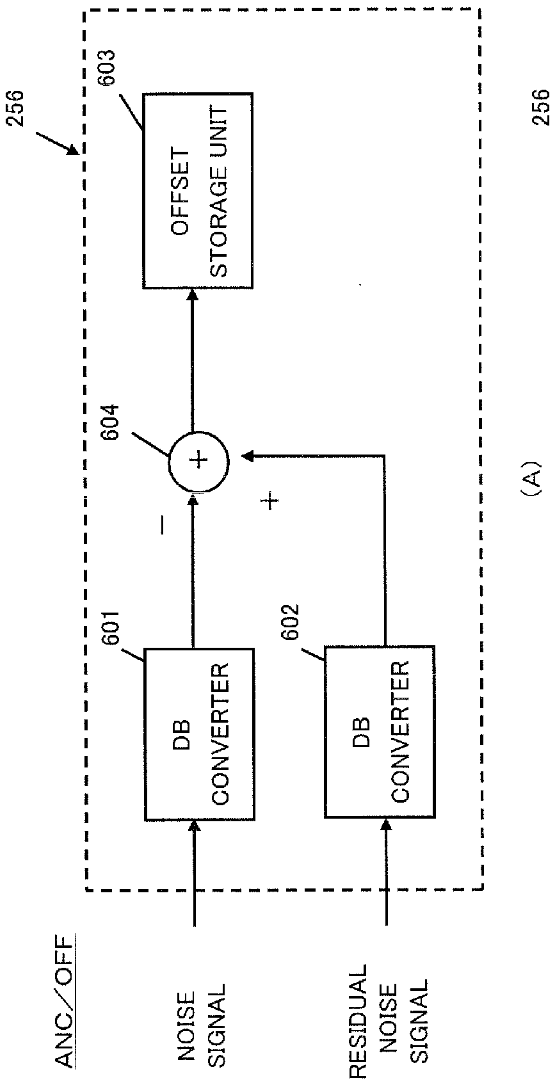

256
603
OFFSET STORAGE UNIT
604
+
−
+
601
DB CONVERTER
602
DB CONVERTER
ANC/OFF
NOISE SIGNAL
RESIDUAL NOISE SIGNAL
(A)

Fig.6A

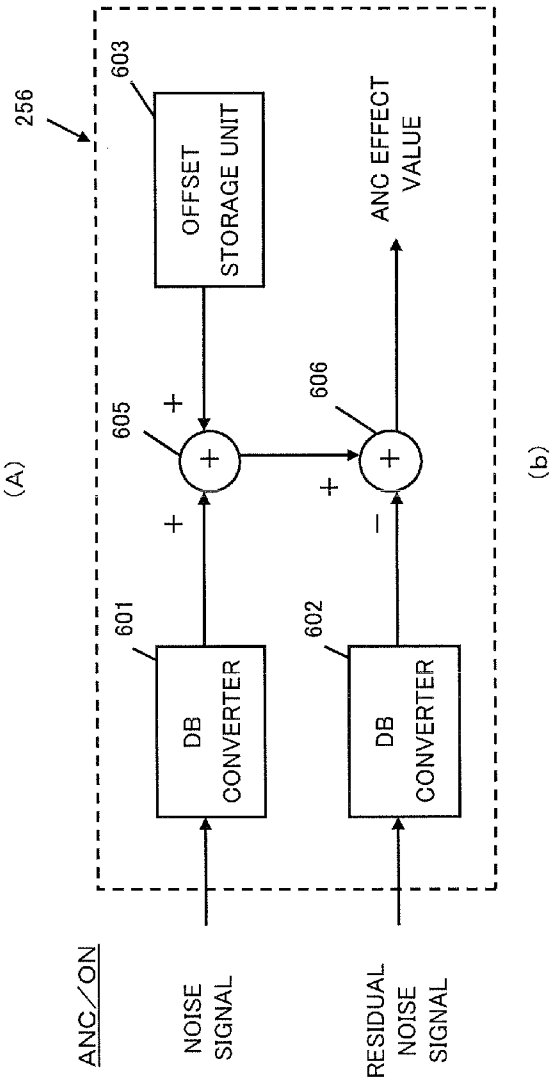
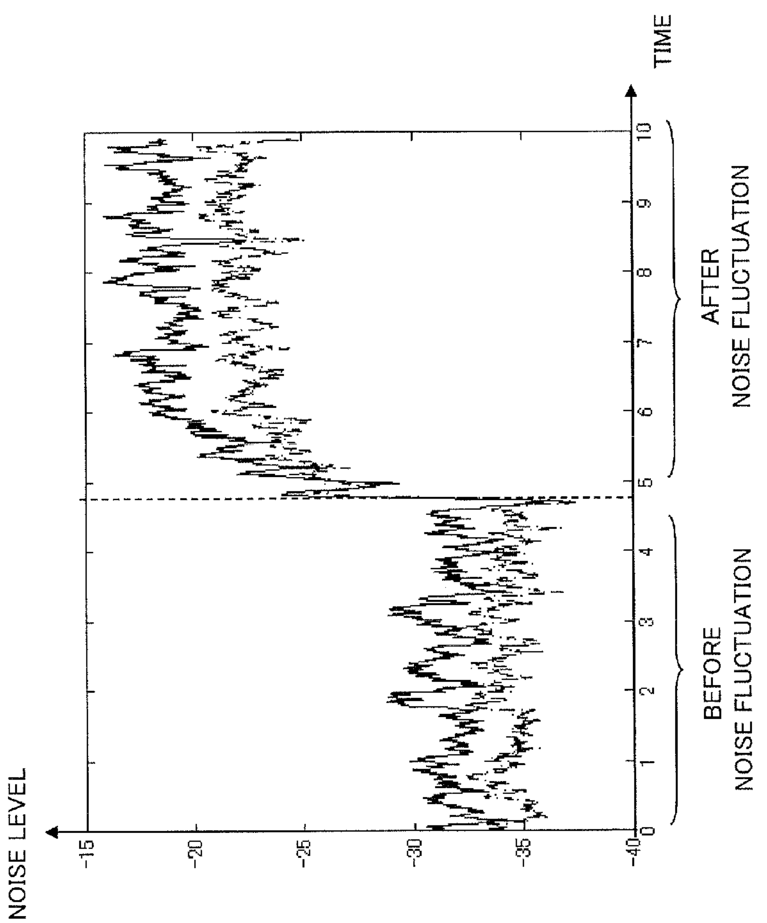

256
603
OFFSET STORAGE UNIT
ANC EFFECT VALUE
605
606
+
+
+
−
601
DB CONVERTER
602
DB CONVERTER
ANC/ON
NOISE SIGNAL
RESIDUAL NOISE SIGNAL
(b)

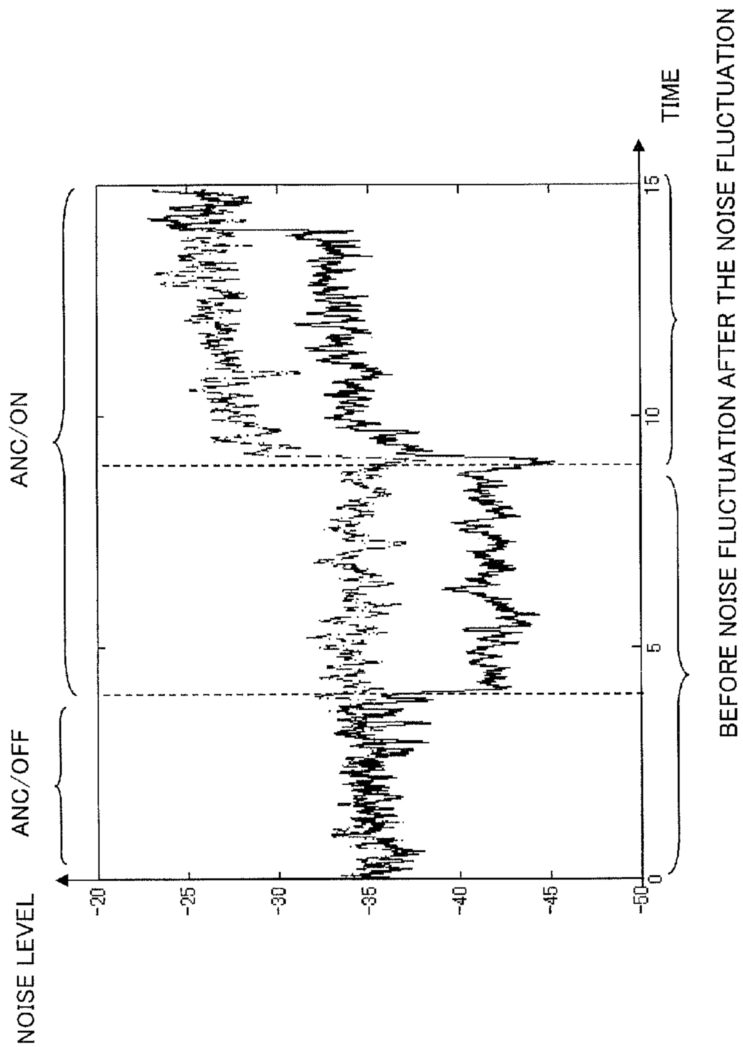
Fig.6B

Fig.7



SOLID LINE :RESIDUAL NOISE LEVEL DETECTED BY RESIDUAL NOISE DETECTING MICROPHONE
BROKEN LINE :NOISE LEVEL DETECTED BY NOISE DETECTING MICROPHONE

Fig.8



SOLID LINE : RESIDUAL NOISE LEVEL ACTUALLY DETECTED BY RESIDUAL NOISE DETECTING MICROPHONE

BROKEN LINE : ESTIMATED VALUE OF NOISE LEVEL THAT WOULD BE DETECTED BY RESIDUAL NOISE DETECTING MICROPHONE IN A CASE OF ANC/OFF

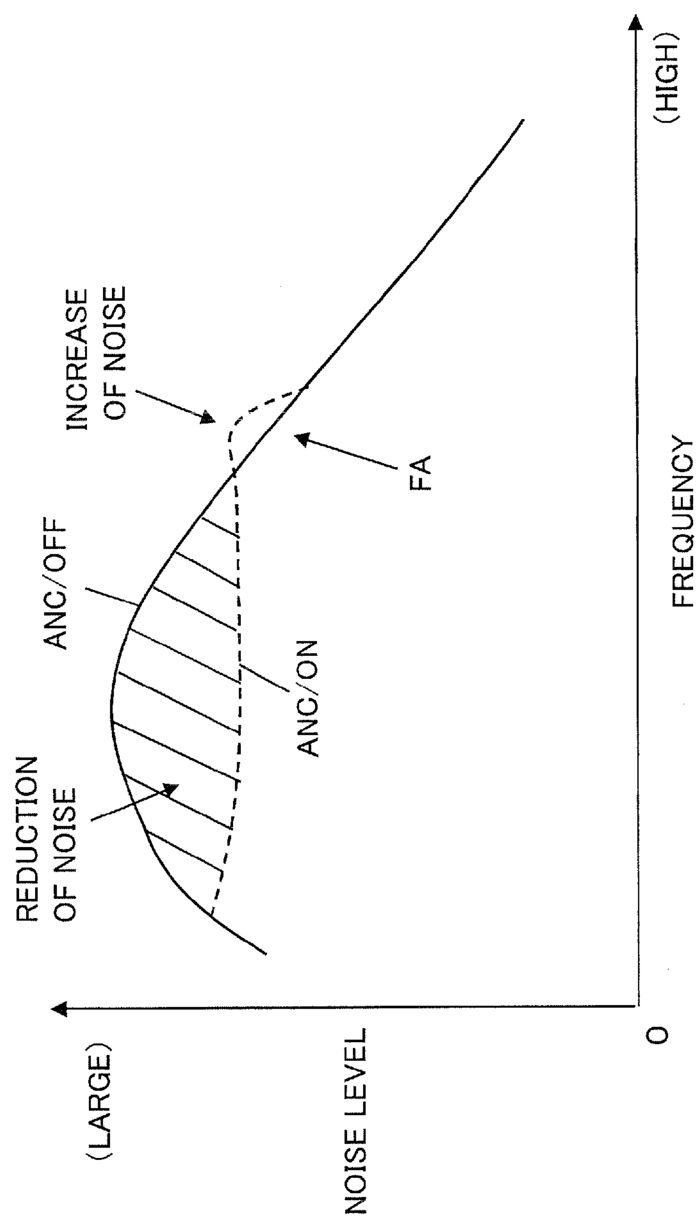

(LARGE)
NOISE LEVEL
0
FREQUENCY
(HIGH)
REDUCTION OF NOISE
ANC/OFF
ANC/ON
INCREASE OF NOISE
FA

Fig.9

NOISE REDUCTION APPARATUS

BACKGROUND

1. Technical Field

The present disclosure relates to a noise reduction apparatus for reducing noises.

2. Related Art

JP-A-2-285799 (Patent Document 1) discloses a basic configuration of a noise reduction apparatus. This noise reduction apparatus outputs a control sound of which phase is opposite to a noise from a noise source in a noise reduction position (control point). As a result, noises at the control point are reduced.

JP-A-7-253788 (Patent Document 2) discloses a noise reduction apparatus that estimates a noise reduction amount and controls an ON/OFF state of the noise reduction apparatus according to the estimated noise reduction amount. Specifically, the noise reduction apparatus has a speaker for outputting a control sound, a first microphone provided on a noise source side of the speaker, and a second microphone provided on an opposite noise source side (for example, the control point) of the speaker. The noise reduction apparatus detects a noise when the noise source operates and a noise (dark noise) when neither the noise source nor the noise reduction apparatus operates through the respective microphones, and estimates the noise reduction amount based on the detected noises. The noise reduction apparatus controls the ON/OFF state of the noise reduction apparatus according to the estimated noise reduction amount.

SUMMARY

A noise reduction apparatus according to the present disclosure includes a first noise detecting microphone operable to detect a noise on a position different from a noise reduction target position, a second noise detecting microphone operable to detect a noise on the noise reduction target position, a control sound output unit operable to generate a control sound for reducing the noise on the noise reduction target position based on an output from the first noise detecting microphone and an output from the second noise detecting microphone to output the control sound, and a noise reduction amount calculator operable to calculate a reduction amount of the noise on the noise reduction target position based on the output from the first noise detecting microphone and the output from the second noise detecting microphone. The noise reduction amount calculator includes a difference calculator operable to obtain a difference between a level of the noise detected by the first noise detecting microphone and a level of the noise detected by the second noise detecting microphone in a state where the control sound output unit does not output the control sound, a storage unit operable to store the difference calculated by the difference calculator, an estimated noise value calculator operable to estimate a noise level that is to be detected by the second noise detecting microphone in the state where the control sound output unit does not output the control sound, based on the level of the noise detected by the first noise detecting microphone in a state where the control sound output unit outputs the control sound and the difference stored in the storage unit, and a reduction amount calculator operable to calculate a noise reduction amount on the noise reduction target position, based on the estimated noise value calculated by the estimated noise value calculator and the level of the noise detected by the second noise detecting microphone in the state where the control sound output unit outputs the control sound.

The noise reduction apparatuses of Patent Documents 1 and 2 occasionally give uncomfortable feelings to users during a noise reduction operation.

The present disclosure provides a noise reduction apparatus capable of reducing uncomfortable feelings to be given to users during an operation of the noise reduction apparatus.

The noise reduction apparatus of the present disclosure can reduce an uncomfortable feeling to be given to a user during a noise reduction operation.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a block diagram illustrating a basic configuration illustrating a noise reduction apparatus according to a first embodiment.

FIGS. **2**A to **2**C are diagrams illustrating a seat where the noise reduction apparatus is installed.

FIG. **3** is a block diagram illustrating a configuration of a noise controller of the noise reduction apparatus.

FIGS. **4**A and **4**B are explanatory diagrams illustrating an effect produced due to an averaging unit.

FIG. **5** is a block diagram illustrating a configuration of the noise controller of the noise reduction apparatus according to a second embodiment.

FIGS. **6**A and **6**B are block diagrams illustrating a configuration of a noise reduction effect determiner of the noise reduction apparatus.

FIG. **7** is a diagram illustrating a time change in a noise level in aircraft.

FIG. **8** is a diagram describing an effect of the noise reduction effect determiner in the noise reduction apparatus.

FIG. **9** is a diagram describing an effect of the noise reduction apparatus according to another embodiment.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Embodiments will be described in detail below with reference to the drawings as necessary. Description that is more detailed than necessity will be occasionally omitted. For example, detailed description about already well-known matters and overlapped description about substantially identical configurations will be occasionally omitted. This is for avoiding the following description from being more redundant than necessity and making understanding of those skilled in the art easy.

The inventors provide the accompanying drawings and the following description in order to have those skilled in the art sufficiently understand the present disclosure, and thus the disclosure is not intended to limit the subject matter described in the claims.

BACKGROUND OF THE PRESENT DISCLOSURE

Before a noise reduction apparatus according to the present embodiment is described, the background of the present disclosure is described.

For example, in aircraft and railway vehicles, information such as voice service is provided to users who have taken their seats. For this reason, noises at the seats become a problem.

Examples of noises in the aircraft are noises generated from devices for producing a thrust force, such as an engine and a propeller, and noises relating to aerial flow of a wind noise generated according to transfer of aircraft through airspace. Such noises generated from respective noise sources are transmitted into a cabin of the aircraft, and give an uncomfortable feeling to the passenger and interfere with the voice service.

In order to reduce noises in the cabin of the aircraft, noise insulation materials (passive damping unit) such as barrier materials and absorbers are conventionally arranged between the cabin and the noise sources.

However, countermeasures against the noises using the noise insulation materials cause the following problems. That is, the barrier materials and the absorbers generally have high-density. Such high-density materials cause an increase in weight of the aircraft. The increase in weight causes deterioration in fuel efficiency and decrease in a flight range, and leads to deteriorations in economic efficiency and functions of the aircraft. The barrier materials and the absorbers are easily damaged, and thus these structural materials have a problem in strength. Further, they have a problem in that a design such as texture is deteriorated.

In order to cope with these problems, in recent years, there is proposed an active attenuation unit for outputting control sounds of which phase is opposite to noises from noise sources at a control point to reduce the noises at the control point. Examples of the active attenuation unit are described in Patent Documents 1 and 2.

However, the noise reduction apparatuses in Patent Documents 1 and 2 occasionally give uncomfortable feelings to users during the operation of the noise reduction apparatuses as described above.

Specifically, noises from noise sources may occasionally fluctuate. When the fluctuation in noises occurs, in the noise reduction apparatus of Patent Document 1, noises from the noise sources and control sounds occasionally have the same phase, and thus noises at the control point occasionally increase. That is, noises cannot be reduced, thereby giving uncomfortable feelings to the users.

In the noise reduction apparatus of Patent Document 2, ON/OFF control of the noise reduction apparatus can be made according to a noise reduction amount. However, when the noise reduction amount is obtained, a noise value on a position of a second microphone that is generated when the noise sources operate and the noise reduction apparatus is stopped should be obtained. For this reason, the noise reduction apparatus is required to be stopped at a constant cycle. While the noise reduction apparatus is stopped, noises from the noise sources are transmitted directly. As a result, uncomfortable feelings may be given to the users.

The present disclosure adopts the following configuration in order to solve above problem.

The noise reduction apparatus according to embodiments will be described below with reference to the drawings.

First Embodiment

1. Configuration

1-1. Configuration of Noise Reduction Apparatus

The first embodiment will describe a case where the noise reduction apparatus of the present disclosure is installed in seats of the aircraft.

FIG. **1** is a block diagram illustrating a basic configuration of the noise reduction apparatus according to the first embodiment. FIGS. **2**A to **2**C are diagrams illustrating a seat where the noise reduction apparatus according to the first embodiment is installed. Specifically, FIG. **2**A is a front view of the seat. FIG. **2**B is a side view of the seat. FIG. **2**C is a rear view of the seat.

As shown in FIG. **1**, a noise reduction apparatus **100** includes noise detecting microphones **101** to **120**, noise controllers **2001-1** to **2020-1**, **2001-2** to **2020-2**, **2001-3** to **2020-3**, and **2001-4** to **2020-4**, adders **301** to **304**, control speakers **401** to **404**, and residual noise detecting microphones **501** and **502**.

As shown in FIGS. **2**A to **2**C, the noise detecting microphones **101** to **120** are decentrally arranged on a side portion and the like of a seat **600**, and detect noises from a circumference of the seat **600**.

The residual noise detecting microphones **501** and **502** are arranged at ears of a user A. In the first embodiment, positions of the ears of the user A are set as control points.

The control speakers **401** to **404** are arranged on positions located above the seat **600**, which is near the ears of the user (passenger) A and at approximately the same height as the ears.

Returning to FIG. **1**, the noise detecting microphones **101** to **120** detect the noises generated from noise sources, and convert the noises into electric signals to output the signals.

The residual noise detecting microphones **501** and **502** detect residual noises at the control points.

The noise controllers **2001-1** to **2020-1**, **2001-2** to **2020-2**, **2001-3** to **2020-3**, and **2001-4** to **2020-4** generate control sound signals based on noise signals from the noise detecting microphones **101** to **120** and residual noise signals from the residual noise detecting microphones **501** and **502** so that levels of the residual noises detected by the residual noise detecting microphones **501** and **502** are minimum. That is, the noise controllers perform feedback control. As a result, even when a noise environment changes, the noise level on positions near the ears of the user A can be minimum.

The adder **301** adds the control sound signals output from the noise controllers **2001-1** to **2020-1**, and outputs the added signal to the control speaker **401**. The adder **302** adds control sound signals output from the noise controllers **2001-2** to **2020-2**, and outputs the added signal to the control speaker **402**. The adder **303** adds control sound signals output from the noise controllers **2001-3** to **2020-3**, and outputs the added signal to the control speaker **403**. The adder **304** adds control sound signals output from the noise controllers **2001-4** to **2020-4**, and outputs the added signal to the control speaker **404**.

The control speaker **401** converts the control sound signal from the adder **301** into a sound wave, and outputs the sound wave. The control speaker **402** converts the control sound signal from the adder **302** into a sound wave, and outputs the sound wave. The control speaker **403** converts the control sound signal from the adder **303** into a sound wave, and outputs the sound wave. The control speaker **404** converts the control sound signal from the adder **304** into a sound wave, and outputs the sound wave.

When the control sound is output from the control speaker **401**, the residual noise detecting microphones **501** and **502** at the control points detect noises (residual noises) that are generated by interference between noises from the noise sources and the control sound from the control speaker **401**. For example, when the noises from the noise sources and the control sound from the control speaker **401** have opposite phases at the control points, the residual noise detecting microphones **501** and **502** detect residual noises of which levels are lower than that of the noises from the noise sources. When the noises and the control sound have the same phase at the control points, the residual noise detecting microphones **501** and **502** detect residual noises of which levels are higher than the levels of the noises from the noise sources. When the control sound is not output from the control speaker **401**, the residual noise detecting microphones **501** and **502** at the control points detect the noises transmitted from the noise sources as residual noises.

The residual noise signals from the residual noise detecting microphones **501** and **502** are input into the noise controllers **2001-1** to **2020-1**, **2001-2** to **2020-2**, **2001-3** to **2020-3**, and **2001-4** to **2020-4**, respectively. The noise controllers perform feedback with respect to a result of the operation of the noise reduction apparatus **100**.

The operation of the noise reduction apparatus **100** will be described in detail below.

The noise signal from the noise detecting microphone **101** is output to the noise controllers **2001-1** to **2001-4**. The noise signal from the noise detecting microphone **102** is output to the noise controllers **2002-1** to **2002-4**. Similarly, the noise signals from the noise detecting microphones **103** to **120** are output to the noise controllers **2003-1** to **2003-4**, **2004-1** to **2004-4**, . . . **2020-1** to **2020-4**, respectively.

A transfer function at the time when a sound wave is transferred from the control speaker **401** to the residual noise detecting microphone **501**, and a transfer function at the time when a sound wave is transferred from the control speaker **401** to the residual noise detecting microphone **502** are set in the noise controller **2001-1**. The transfer functions are set by using, for example, Filtered-X_LMS method.

The noise controller **2001-1** obtains a filter coefficient that is applied to an adaptive filter in the noise controller **2001-1** using the set transfer functions. At this time, the noise controller **2001-1** obtains the filter coefficient that makes the levels of the residual noise signals output from the residual noise detecting microphones **501** and **502** minimum. The noise controller **2001-1** updates a current filter coefficient based on the newly obtained filter coefficient.

Similarly to the noise controller **2001-1**, a transfer function at the time when a sound wave is transferred from the control speaker **401** to the residual noise detecting microphone **501**, and a transfer function at the time when a sound wave is transferred from the control speaker **401** to the residual noise detecting microphone **502** are set in the noise controller **2002-1**. The noise controller **2002-1** obtains a filter coefficient to be applied to an adaptive filter in the noise controller **2002-1**. At this time, the noise controller **2002-1** obtains the filter coefficient for making the residual noise signals output from the residual noise detecting microphones **501** and **502** minimum. The noise controller **2002-1** updates a current filter coefficient based on the newly obtained filter coefficient.

Similarly, in the noise controllers **2003-1** to **2020-1**, a transfer function at the time when a sound wave is transferred from the control speaker **401** to the residual noise detecting microphone **501**, and a transfer function at the time when a sound wave is transferred from the control speaker **401** to the residual noise detecting microphone **502** are set. The noise controllers **2003-1** to **2020-1** obtain filter coefficients to be applied to adaptive filters in the noise controllers **2003-1** to **2020-1**. At this time, the noise controllers **2003-1** to **2020-1** obtain the filter coefficients for making the residual noise signals output from the residual noise detecting microphones **501** and **502** minimum. The noise controllers **2003-1** to **2020-1** update current filter coefficients based on the newly obtained filter coefficients.

In the noise controllers **2001-2** to **2020-2**, a transfer function at the time when a sound wave is transferred from the control speaker **402** to the residual noise detecting microphone **501**, and a transfer function at the time when a sound wave is transferred from the control speaker **402** to the residual noise detecting microphone **502** are set. The noise controllers **2001-2** to **2020-2** obtain the filter coefficients to be applied to adaptive filters in the noise controllers **2001-2** to **2020-2**. At this time, the noise controllers **2001-2** to **2020-2** obtain the filter coefficients for making the residual noise signals output from the residual noise detecting microphones **501** and **502** minimum. The noise controllers **2001-2** to **2020-2** update current filter coefficients based on the newly obtained filter coefficients.

In the noise controllers **2001-3** to **2020-3**, a transfer function at the time when a sound wave is transferred from the control speaker **403** to the residual noise detecting microphone **501**, and a transfer function at the time when a sound wave is transferred from the control speaker **403** to the residual noise detecting microphone **502** are set. The noise controllers **2001-3** to **2020-3** obtain filter coefficients to be applied to adaptive filters in the noise controllers **2001-3** to **2020-3**. At this time, the noise controllers **2001-3** to **2020-3** obtain the filter coefficients for making the residual noise signals output from the residual noise detecting microphones **501** and **502** minimum. The noise controllers **2001-3** to **2020-3** update current filter coefficients based on the newly obtained filter coefficients.

In the noise controllers **2001-4** to **2020-4**, a transfer function at the time when a sound wave is transferred from the control speaker **404** to the residual noise detecting microphone **501**, and a transfer function at the time when a sound wave is transferred from the control speaker **404** to the residual noise detecting microphone **502** are set. The noise controllers **2001-4** to **2020-4** obtain the filter coefficients to be applied to adaptive filters in the noise controllers **2001-4** to **2020-4**. At this time, the noise controllers **2001-4** to **2020-4** obtain filter coefficients for making the residual noise signals output from the residual noise detecting microphones **501** and **502** minimum. The noise controllers **2001-4** to **2020-4** update current filter coefficient based on the newly obtained filter coefficients.

The noise controllers **2001-1** to **2020-1** give signal processes to the input noise signals, respectively, using the updated filter coefficients to generate control sound signals, and output the generated control sound signals to the adder **301**. The adder **301** adds the control sound signals output from the noise controllers **2001-1** to **2020-1**, and outputs the added signal to the control speaker **401**. The control speaker **401** outputs the control sound to the control point based on the control sound signal from the adder **301**.

The noise controllers **2001-2** to **2020-2** give signal processes to the input noise signals, respectively, using the updated filter coefficients to generate control sound signals, and output the generated control sound signals to the adder **302**. The adder **302** adds the control sound signals output from the noise controllers **2001-2** to **2020-2**, and outputs the added signal to the control speaker **402**. The control speaker **402** outputs the control sound to the control point based on the control sound signal from the adder **302**.

The noise controllers **2001-3** to **2020-3** give signal processes to the input noise signals, respectively, using the updated filter coefficients to generate control sound signals, and output the generated control sound signals to the adder **303**. The adder **303** adds the control sound signals output from the noise controllers **2001-3** to **2020-3** to output the added signal to the control speaker **403**. The control speaker **403** outputs a control sound to the control point based on the control sound signal from the adder **303**.

The noise controllers **2001-4** to **2020-4** give signal processes to the input noise signals, respectively, using the updated filter coefficients to generate control sound signals, and output the generated control sound signals to the adder **304**. The adder **304** adds the control sound signals output from the noise controllers **2001-4** to **2020-4**, and outputs the added signal to the control speaker **404**. The control speaker **404** outputs a control sound to the control point based on the control sound signal from the adder **304**.

The feedback control is performed by the above processes so that the residual noises after the noise reduction become minimum. As a result, the noises at the control point, namely, at the ears of the user A can be reduced.

The first embodiment describes the case of using the adaptive filters, but when fluctuations in a frequency and a level of noises hardly occur or are small, fixed-type filters may be used. Also in this case, the noise reduction effect can be obtained.

1-2. Configuration of Noise Controller

Configurations of the noise controllers **2001-1** to **2001-4**, **2002-1** to **2002-4**, . . . **2020-1** to **2020-4** will be described.

FIG. **3** is a block diagram illustrating the configurations of the noise controllers. The noise controllers **2001-1** to **2001-4**, **2002-1** to **2002-4**, **2020-1** to **2020-4** described with reference to FIG. **1** have the same internal circuit configuration. For this reason, the noise controller **2001-1** will be described below as an example. FIG. **3** illustrates the noise detecting microphone **101**, the adder **301**, the control speaker **401**, and the residual noise detecting microphones **501** and **502** that are related to the noise controller **2001-1**, out of the noise detecting microphones **101** to **120**, the adders **301** to **304**, the control speakers **401** to **404**, and the residual noise detecting microphones **501** and **502**. Since the configuration after the residual noise detecting microphone **501** is identical to the configuration after the residual noise detecting microphone **502**, only the configuration after the residual noise detecting microphone **501** will be described.

The noise controller **2001-1** is provided with A/D converters **231** and **232**, an adaptive filter **201**, a filter coefficient calculator **233**, a D/A converter **234**, an averaging unit **235** and a noise reduction effect determiner **236**. The A/D converters **231** and **232**, the adaptive filter **201**, the filter coefficient calculator **233**, the D/A converter **234**, the adder **301** and the control speaker **401** configure a control sound output unit **200**.

The A/D converter **231** A/D-converts a noise signal from the noise detecting microphone **101**, and outputs the converted signal to the adaptive filter **201** and the filter coefficient calculator **233**.

The A/D converter **232** A/D converts a residual noise signal from the residual noise detecting microphone **501**, and outputs the converted signal to the filter coefficient calculator **233** and the averaging unit **235**.

The D/A converter **234** outputs the output from the adaptive filter **201** to the control speaker **401** via the adder **301**.

The adaptive filter **201** is an FIR (Finite Impulse Response) filter. The FIR filter has a multistage tap, and can freely set filter coefficients of the respective taps.

The filter coefficient calculator **233** inputs a noise signal output from the noise detecting microphone **101** via the A/D converter **231**, and a residual noise signal output from the residual noise detecting microphone **501** via the A/D converter **232**. The filter coefficient calculator **233** obtains a filter coefficient for making a residual noise detected at the control point based on the noise signal and the residual noise signal minimum, and outputs the filter coefficient to the adaptive filter **201**. Specifically, the filter coefficient calculator **233** obtains the filter coefficient for making the control speaker **401** to generate a control sound of which phase is opposite to that of noises from the noise sources on the installed position of the residual noise detecting microphone **501**, and outputs the filter coefficient to the adaptive filter **201**.

The averaging unit **235** averages level of the residual noise signal input from the residual noise detecting microphone **501**. As a result, instant fluctuations in the level of the residual noise signal can be reduced. For example, the averaging unit **235** obtains an average value of the level of the residual noise signal for a predetermined time before and after a target time. The averaging unit **235** may carry out the averaging through another method.

The noise reduction effect determiner **236** calculates a noise reduction amount using the residual noise signal level averaged by the averaging unit **235**, namely, the residual noise signal level from which an influence of the instant fluctuations is eliminated. For example, the noise reduction effect determiner **236** saves the residual noise signal level at the ANC/OFF time, and calculates a noise reduction amount at the ANC/ON time based on the residual noise signal level at the ANC/ON time, and the saved residual noise signal level at the ANC/OFF time. The noise reduction effect determiner **236** determines the noise reduction effect based on the noise reduction amount.

When the calculated noise reduction amount is a predetermined value or more, the noise reduction effect determiner **236** determines that the noise reduction effect is present, and instructs the adaptive filter **201** to continue the ANC operation (ANC/ON). On the contrary, when the calculated noise reduction amount is a predetermined value or less, the noise reduction effect determiner **236** determines that the noise reduction effect is not satisfactory, and instructs the adaptive filter **201** to stop the ANC operation (ANC/OFF).

For example, when the residual noise signal level detected by the residual noise detecting microphone **501** at the ANC/ON time is larger than the saved residual noise signal level the ANC/OFF time, it is considered that the residual noises increase due to ANC/ON. In this case, a shift to ANC/OFF can eliminate the increase in the residual noise level (an increase in noises), and thus uncomfortable feelings are not given to users.

2. Effect Obtained by Providing Averaging Unit

FIGS. **4**A and **4**B are explanatory diagrams illustrating the effect obtained by the averaging unit **235**. Specifically, FIG. **4**A is a diagram illustrating the residual noise level actually measured in a case where the averaging unit **235** is not provided, and FIG. **4**B is a diagram illustrating the residual noise level actually measured in a case where the averaging unit **235** is provided (FIG. **4**B). In the case where the averaging unit **235** is not provided and in the case where the averaging unit **235** is provided, the residual noise levels were measured at the ANC/OFF time and the ANC/ON time.

When the averaging unit **235** is not provided, as shown in FIG. **4**A, the instant fluctuation in the noise level is large. For this reason, it is difficult to accurately estimate a difference between the noise levels at the ANC/OFF time and the ANC/ON time, namely, the noise reduction effect.

On the contrary, when the averaging unit **235** is provided as in the first embodiment, the instant fluctuation is nearly eliminated as shown in FIG. **4**B. As a result, the difference between the noise levels at the ANC/OFF time and at the ANC/ON time, namely, the noise reduction amount (the noise reduction effect) can be accurately estimated.

Instead of the shift to ANC/OFF, parameters relating to the design of the filter coefficients may be changed to be re-optimized. The parameters relating to the design of the filter coefficients are, for example, a learning speed μ in the Filtered-X_LMS method. In this case, the noise reduction effect determiner **236** may output an instruction signal for changing and optimizing the parameters relating to the design of the filter coefficients to the filter coefficient calculator **233** as shown by a broken line in FIG. **3**.

Instead of the shift to ANC/OFF, an updating amount of the filter coefficient to be output from the filter coefficient calculator **233** to the adaptive filter **201** is set to 0, so that the adaptive filter **201** can function as the fixed filter. In this case, the noise reduction effect determiner **236** may output an instruction signal for setting the updating amount of the filter coefficient to 0 as shown by the broken line in FIG. **3** to the filter coefficient calculator **233**.

The first embodiment has described the case in which the noise level at the ANC/ON time is compared with the noise level at the ANC/OkF time, but the noise level at the ANC/ON time may be compared with a predetermined value. As a result, for example, only when the noise level at the ANC/ON time is very large, the state can be changed to the ANC/OFF. Alternatively, for example, when the noise level at the ANC/ON time is slightly large, namely, when the noise reduction effect is deteriorated only slightly, the state can be changed to ANC/OFF.

Second Embodiment

1. Configuration

FIG. **5** is a block diagram illustrating a configuration of the noise controller of a noise reduction apparatus **150** according to a second embodiment.

The noise reduction apparatus **150** according to the second embodiment is provided with the noise controller **2501-1** instead of the noise controller **2001-1** of the noise reduction apparatus **100**. The entire configuration of the noise reduction apparatus is similar to that in the first embodiment in FIGS. **2**A to **2**C, and in FIGS. **2**A to **2**C, the noise controllers **2501-1** to **2501-4**, **2502-1** to **2502-4**, . . . **2520-1** to **2520-4** are provided instead of the noise controllers **2001-1** to **2001-4**, **2002-1** to **2002-4**, . . . **2020-1** to **2020-4**. Since the plurality of the noise controllers **2501-1** to **2501-4**, **2502-1** to **2502-4**, . . . **2520-1** to **2520-4** have the same configuration in the internal circuit, the noise controller **2501-1** will be described below as an example. FIG. **5** illustrates the noise detecting microphone **101**, the adder **301**, the control speaker **401**, and the residual noise detecting microphone **501** that are related to the noise controller **2501-1**, out of the noise detecting microphones **101** to **120**, the adders **301** to **304**, the control speakers **401** to **404**, and the residual noise detecting microphones **501** and **502** shown in FIGS. **2**A to **2**C.

In the noise controller **2501-1** according to the second embodiment, the noise signal from the noise detecting microphone **101** is input into an averaging unit **255** via the A/D converter **231**. The signal averaged by the averaging unit **255** is input into a noise reduction effect determiner **256**. The noise reduction effect determiner **256** determines the noise reduction effect based on the noise signal from the noise detecting microphone **101** and the residual noise signal from the residual noise detecting microphone **501**.

FIGS. **6**A and **6**B are block diagrams illustrating a configuration of the noise reduction effect determiner **256** according to the second embodiment. The noise reduction effect determiner **256** can switch the circuit configuration between the ANC/OFF and the ANC/ON. FIG. **6**A illustrates the circuit configuration at the ANC/OFF time, and FIG. **6**B illustrates the circuit configuration at the ANC/ON time.

As shown in FIG. **6**A, at the ANC/OFF time, the noise reduction effect determiner **256** has dB converters **601** and **602**, an adder **604**, and an offset storage unit **603**. The dB converter **601** converts the level of the noise signal averaged by the averaging unit **255** into a dB value (decibel value, the noise level) to output the dB value. The dB converter **602** converts the level of the residual noise signal averaged by the averaging unit **255** into a dB value to output the dB value. The adder **604** adds a value obtained by inverting an output from the dB converter **601** to an output from the dB converter **602** to output the added value. The offset storage unit **603** stores an output from the adder **604**. That is, the adder **604** outputs a level (offset value) of a difference between the noise level and the residual noise level.

On the contrary, at the ANC/ON time, the noise reduction effect determiner **256** includes the dB converters **601** and **602**, the adders **605** and **606**, and the offset storage unit **603** as shown in FIG. **6**B. The dB converter **601** converts a level of a noise detection signal averaged by the averaging unit **255** into a dB value to output the dB value. The dB converter **601** converts a level of a noise signal averaged by the averaging unit **255** into a dB value to output the dB value. The adder **604** adds an output from the dB converter **601** and an output from the offset storage unit **603** to output the added value. The offset storage unit **603** outputs an offset value stored at the ANC/OFF time. In the adder **605**, the value obtained by adding the output from the dB converter **601** and the output from the offset storage unit **603** becomes an estimated value of the level of the noise (estimated noise level) detected by the residual noise detecting microphone in the OFF state of ANC. The adder **606** outputs a value obtained by adding the value obtained by inverting the output from the dB converter **602**, and the output from the adder **604**. In the adder **606**, a value, which is obtained by adding a value obtained by inverting the output from the dB converter **602** (residual noise detection signal estimated value) and a value obtained by inverting the output from the dB converter **602**, becomes a noise reduction value by means of ANC/ON. The noise reduction effect determiner **256** determines the noise reduction effect based on the noise reduction value.

2. Noise Reduction Effect at the Time of Noise Fluctuation

In order to accurately determine the noise reduction effect, even when the levels of the noises generated from the noise sources fluctuate, a difference between the noise level detected by the noise detecting microphone **101** and the noise level detected by the residual noise detecting microphone **501** should not be changed.

FIG. **7** is a diagram illustrating a time change in the noise level in aircraft. In FIG. **7**, a vertical axis represents the noise level (dB), and a horizontal axis represents time (second). A solid line in FIG. **7** indicates the noise level that is detected by the residual noise detecting microphone **501** and is output from the dB converter **602**, and a broken line indicates the noise level that is detected by the noise detecting microphone **101** and is output from the dB converter **602**.

As shown in FIG. **7**, it is found that the difference between the noise level and the residual noise level after the noise fluctuation is approximately the same as the difference between the noise level and the residual noise level before the noise fluctuation. This is considered to be because the noises generated in the aircraft are reflected from walls and shell inside the aircraft and are averaged as a result. That is, a fluctuation in the noises in the aircraft does not locally occur and occurs in a wide range. In this example, a case where noises increase is described, but much the same is true on a case where noises are reduced.

3. Effect Obtained by Noise Reduction Effect Determiner According to Second Embodiment

FIG. **8** is a diagram for describing the effect obtained by the noise reduction effect determiner **256** according to the second embodiment. A solid line in FIG. **8** indicates the level of noises actually detected by the residual noise detecting microphone **501** (hereinafter, suitably referred to as "the actual noise level"). A broken line in FIG. **8** indicates an estimated value of the noise level (hereinafter, suitably referred to as "the estimated noise level") that would be detected by the residual noise detecting microphone **501** in a case of ANC/OFF. A difference between the actual noise level and the estimated noise level becomes the noise reduction amount at the ANC/ON time.

As shown in FIG. **8**, at the ANC/OFF time, the actual noise level actually detected by the residual noise detecting microphone and the estimated noise level have approximately the same values. This represents that the noise level is satisfactorily estimated by the noise reduction effect determiner **256** at the ANC/OFF time. In this state, the shift to ANC/ON reduces the actual noise level (residual noise level) actually detected by the residual noise detecting microphone **501**. The difference between the residual noise level and the estimated noise level becomes the noise reduction amount.

When the level of the noises generated from the noise sources rises at the ANC/ON time, the actual noise level actually detected by the residual noise detecting microphone **501** rises. In the second embodiment, the estimated noise level is estimated based on the actual noise level detected by the noise detecting microphone **101**, but the actual noise level actually detected by the residual noise detecting microphone **501** and the actual noise level actually detected by the noise detecting microphone **101** fluctuate with approximately constant offset values as described with reference to FIG. **7**. For this reason, the shift to ANC/ON enables the estimated noise level detected by the residual noise detecting microphone **501** to be accurately estimated. Therefore, even when the levels of the noises generated from the noise sources fluctuate, the estimated noise levels can be accurately estimated. That is, the noise reduction amount can be accurately estimated whether it is before or after the noise fluctuation.

In the first embodiment, when the levels of the noises from the noise sources change, a defective operation might be performed. For example, when the levels of the noises from the noise sources are large, even if the noise reduction apparatus **100** normally operates, the residual noise after the noise reduction is occasionally louder than the saved noises at the ANC/OFF time. In this case, determination is erroneously made that the noises increase due to the shift to ANC/ON. However, in the second embodiment, the estimated noise level changes according to the levels of the noises from the noise sources. Thus, this problem can be solved.

In order to simplify the description, the case where one noise detecting microphone and one residual noise detecting microphone are provided has been described, but the same effect can be also obtained in a case where a plurality of each of microphones are provided.

4. Conclusion (Configuration, Effect, and the like)

In the second embodiment, the noise reduction apparatus **150** includes:

the noise detecting microphone **101** (a first noise detecting microphone) for detecting noises on a position different from a noise reduction target position;

the residual noise detecting microphone **501** (a second noise detecting microphone) for detecting noises on the noise reduction target position;

the control sound output unit **200** (a control sound output unit) for generating a control sound for reducing the noises on the noise reduction target position, based on an output from the noise detecting microphone **101** and an output from the residual noise detecting microphone **501** to output the control sound; and

the noise reduction effect determiner **256** (a noise reduction amount calculator) for calculating a reduction amount of the noises on the noise reduction target position, based on the output from the noise detecting microphone **101** and the output from the residual noise detecting microphone **501**, wherein

the noise reduction effect determiner **256** includes

the adder **604** (a difference calculator) for obtaining a difference between the noise level detected by the noise detecting microphone **101** and the noise level detected by the residual noise detecting microphone **501** in a state where the control sound output unit **200** does not output a control sound,

the offset storage unit **603** (a storage unit) for storing the difference calculated by the adder **604**,

the adder **605** (an estimated noise value calculator) for estimating the noise level that is to be detected by the residual noise detecting microphone **501** in the state where the control sound output unit **200** does not output the control sound, based on the noise level detected by the noise detecting microphone **101** in a state where the control sound output unit **200** outputs the control sound and the difference stored in the offset storage unit **603**, and

the adder **606** (a reduction amount calculator) for calculating the noise reduction amount on the noise reduction target position, based on the estimated noise value calculated by the adder **605** and the level of the residual noise detected by the residual noise detecting microphone **501** in a state where the control sound output unit **200** outputs the control sound.

Accordingly, when obtaining the noise reduction amount on the noise reduction target position, the noise reduction apparatus **150** does not have to be stopped. For this reason, an uncomfortable feeling given to the user can be reduced.

In the second embodiment, the noise reduction apparatus **150** includes the noise reduction effect determiner **256** (a noise controller) for controlling an output state of the control sound in the control sound output unit **200** based on the noise reduction amount calculated by the noise reduction effect determiner **256**.

Accordingly, the output state of the control sound in the control sound output unit **200** is controlled based on the noise reduction amount. For this reason, for example, when the noises detected by the residual noise detecting microphone **501** are louder than the noises detected by the noise detecting microphone **101**, the output of the control sound can be stopped.

In the noise reduction apparatus **150** according to the second embodiment, when the noise reduction amount calculated by the noise reduction effect determiner **256** (noise reduction amount calculator) is equal to or less than a threshold, the noise reduction effect determiner **256** (a noise controller) instructs the control sound output unit **200** to stop output of a control sound.

Accordingly, when the noise reduction amount is equal to or less than the threshold, the output of the control sound is stopped. For this reason, the output of the control sound can be reliably stopped.

In the noise reduction apparatus **150** according to the second embodiment, the control sound output unit **200** can change a characteristic of the control sound, and when the noise reduction amount calculated by the noise reduction effect determiner **256** (noise reduction amount calculator) is equal to or less than the threshold, the noise reduction effect determiner **256** (the noise controller) may instruct the control sound output unit **200** to change the characteristic of the output control sound.

Accordingly, when the noise reduction amount is equal to or less than the threshold, the output of the control sound is stopped. For this reason, the output of the control sound can be reliably stopped.

In the second embodiment, the noise reduction apparatus **150** further includes the averaging unit **255** (a fluctuation suppressing unit) for absorbing an instant fluctuation in the outputs from the noise detecting microphone **101** and the residual noise detecting microphone **501**, and then outputting the outputs from the noise detecting microphone **101** and the residual noise detecting microphone **501**.

Accordingly, the outputs from the noise detecting microphone **101** and the residual noise detecting microphone **501** are input into the noise reduction effect determiner **256** of which instant fluctuation is absorbed. For this reason, calculating accuracy of the noise reduction amount is improved.

In the noise reduction apparatus **150** according to the second embodiment, the averaging unit **255** averages the outputs from the noise detecting microphone **101** and the residual noise detecting microphone **501** in a time region.

Accordingly, the outputs from the noise detecting microphone **101** and the residual noise detecting microphone **501** are averaged in the time region. For this reason, the instant fluctuation can be absorbed. Therefore, the calculating accuracy of the noise reduction amount is improved.

The fluctuation suppressing unit may be a low-pass filter that allows components in a predetermined frequency range on a low range side of the outputs from the noise detecting microphone **101** and the residual noise detecting microphone **501** to pass.

Accordingly, the outputs from the noise detecting microphone **101** and the residual noise detecting microphone **501** in the predetermined frequency range on the low range side pass. That is, components in a frequency range of a high range side do not pass or the passing is suppressed. For this reason, the instant fluctuation can be absorbed. Therefore, the calculating accuracy of the noise reduction amount is improved.

Another Embodiment

The first and second embodiments have been described as the examples of the technique disclosed in the present application. However, the technique in this disclosure is not limited thereto, and the present disclosure can be applied also to embodiments where modifications, replacements, addition, and omission are carried out. Further, the components described in the first and second embodiments may be combined to provide a new embodiment.

The first and second embodiments have described the case where one noise controller is connected to one noise detecting microphone **101**. However, a plurality of noise detecting microphones may be provided. In this case, the fluctuation suppressing unit calculates an average value of the outputs from the plurality of noise detecting microphones, and the calculated average value may be used as the outputs from the noise detecting microphones. In this case, the average value of the outputs from the plurality of noise detecting microphones can be used as outputs from the noise detecting microphones. Such a configuration improves the estimating accuracy of the noise levels on the positions of the residual noise detecting microphones.

In the second embodiment, the levels of the noise signals from the noise sources and the level of the residual noise signal detected by the residual noise detecting microphone are converted into dB values (the noise levels), and the value obtained by adding the dB values is used as an offset value. This offset value is added to the current noise level, so that the estimated noise level is obtained, but the present disclosure is not limited thereto. For example, the levels of the residual noise signals detected by the noise detecting microphone **101** and the residual noise detecting microphone **501** are not converted into dB values (the noise levels), but the estimated noise levels may be obtained. For example, a ratio of the levels of the residual noise signals (linear values) detected by the noise detecting microphone **101** and the residual noise detecting microphone **501** is obtained, and the current residual noise level is multiplied by this ratio, so that the estimated noise level may be obtained.

The levels of the noises from the noise sources and the frequency band of the residual noise detected by the residual noise detecting microphone are divided into a plurality of frequency bands, and the noise level and the residual noise level are obtained in each of the frequency bands, so that the noise reduction amount may be obtained in each of the frequency band. FIG. **9** is a diagram for describing an effect of this configuration. A solid line of FIG. **9** indicates the level of the residual noise signal at the ANC/OFF time, and a broken line indicates the level of the residual noise signal at the ANC/ON time. In the example of FIG. **9**, in a middle-low tone range, the level of the residual noise signal at the ANC/ON time is lower than the level of the residual noise signal at the ANC/OFF time. As a result, the noise reduction effect is obtained. However, in a partial frequency band on the high-tone side (a range shown by Fa), the level of the residual noise signal at the ANC/ON time is higher than the level of the noise signal at the ANC/OFF time. As a result, the noise reduction effect is not obtained. When the partial frequency band on the high-tone side includes a frequency band in which the human's sense of hearing is sensitive, a user may have an uncomfortable feeling at the ANC/ON time. However, when the frequency band is not divided and the noise reduction effect is determined, namely, when the noise reduction effect is determined by averaging an entire frequency band, and the determination is made that the noise reduction effect is obtained, ANC/OFF is not carried out. That is, a state where the user has an uncomfortable feeling continues. However, when the frequency band is divided and the noise reduction effect is determined as in this example, ANC/OFF can be carried out when the noise reduction effect is not obtained in the frequency band in which the human's sense of hearing is sensitive. As a result, the user can be prevented from having the uncomfortable feeling.

The effect of ANC may be visually carried to the user by displaying the noise reduction amount (the noise reduction effect) on a monitor. For example, when a monitor for viewing movies mounted onto a seat in aircraft is used, the noise reduction effect can be visually carried to the users while a great increase in cost is suppressed.

The embodiments have been described as the examples of the technique in this disclosure. For this reason, the accompanying drawings and the detailed description are provided.

Therefore, the components illustrated in the accompanying drawings and described in the detailed description include not only the components required for solving the problem but also the components that are not required for solving the problem in order to illustrate the above technique. For this reason, even if such unrequired components are illustrated in the accompanying drawings and described in the detailed description, these unrequired components should not be immediately regarded as necessary.

Since the above embodiments are for illustrating the technique in the disclosure, various alternations, replacements, additions, and omissions can be carried out within the scope of claims and an equivalent scope.

INDUSTRIAL APPLICABILITY

The noise reduction apparatus of the present disclosure can be applied to the noise reduction apparatus for reducing noises on the noise reduction target position. Specifically, the present disclosure can be applied to the noise reduction apparatus that is used in spaces such as aircraft, trains, and automobiles that require high comfortability in complicated noise environments.

What is claimed is:

1. A noise reduction apparatus, comprising:

a first noise detecting microphone operable to detect a noise on a position different from a noise reduction target position;

a second noise detecting microphone operable to detect a noise on the noise reduction target position;

a control sound output unit operable to generate a control sound for reducing the noise on the noise reduction target position based on an output from the first noise detecting microphone and an output from the second noise detecting microphone to output the control sound; and

a noise reduction amount calculator operable to calculate a reduction amount of the noise on the noise reduction target position based on the output from the first noise detecting microphone and the output from the second noise detecting microphone, wherein

the noise reduction amount calculator includes

a first calculator operable to obtain a difference between a level of the noise detected by the first noise detecting microphone and a level of the noise detected by the second noise detecting microphone in a state where the control sound output unit does not output the control sound,

a storage unit operable to store the difference calculated by the first calculator,

a second calculator operable to estimate a noise level that is to be detected by the second noise detecting microphone in the state where the control sound output unit does not output the control sound, based on the level of the noise detected by the first noise detecting microphone in a state where the control sound output unit outputs the control sound and the difference stored in the storage unit, and

a third calculator operable to calculate a noise reduction amount on the noise reduction target position, based on the estimated noise value calculated by the second calculator and the level of the noise detected by the second noise detecting microphone in the state where the control sound output unit outputs the control sound.

2. The noise reduction apparatus according to claim **1**, further comprising a noise controller operable to control an output state of the control sound in the control sound output unit based on the noise reduction amount calculated by the noise reduction amount calculator.

3. The noise reduction apparatus according to claim **2**, wherein, when the noise reduction amount calculated by the noise reduction amount calculator is equal to or less than a threshold, the noise controller instructs the control sound output unit to stop output of the control sound.

4. The noise reduction apparatus according to claim **2**, wherein

the control sound output unit can change a characteristic of the control sound,

the noise controller instructs the control sound output unit to change the characteristic of the control sound to be output when the noise reduction amount calculated by the noise reduction amount calculator is equal to or less than the threshold.

5. The noise reduction apparatus according to claim **1**, further comprising a fluctuation suppressing unit operable to suppress an instant fluctuation in the outputs from the first noise detecting microphone and the second noise detecting microphone and output the outputs of which instant fluctuation is suppressed as the outputs from the first noise detecting microphone and the second noise detecting microphone.

6. The noise reduction apparatus according to claim **5**, wherein the fluctuation suppressing unit is a low-pass filter that allows components in a predetermined frequency range in the outputs from the first noise detecting microphone and the second noise detecting microphone to pass.

7. The noise reduction apparatus according to claim **5**, wherein the fluctuation suppressing unit is an averaging unit that averages the outputs from the first noise detecting microphone and the second noise detecting microphone in a time region.

8. The noise reduction apparatus according to claim **5**, wherein

the first noise detecting microphone includes a plurality of noise detecting microphones,

the fluctuation suppressing unit calculates an average value of noise levels detected by the plurality of the noise detecting microphones, and uses the calculated average value as the level of the noise detected by the first noise detecting microphone.

9. The noise reduction apparatus according to claim **1**, further comprising a video output device operable to display information about the noise reduction amount output from the noise reduction amount calculator.

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